

## **Utilisation of iron ore fines in alternative iron making processes - An Indian perspective**

S. CHAKRAVARTY, P. BHATTACHARYA, S. S. CHATTERJEE  
and B. N. SINGH

*Metallurgical Consultants (India) Ltd., Ranchi, India*

### **ABSTRACT**

*Extraction of metallic iron from iron bearing ores is the basis of iron and steel industry. Extensive mechanized mining and advanced beneficiation techniques to meet the oxide feed requirements of Blast Furnace, Direct Reduction and Smelting Reduction processes are resulting in generation of macro and micro fines/slimes (washed fines) in various mine sites of the country. Though a part of the fines, mainly macro ones, in the agglomerated form, that is either as sinter or pellet have found use in various iron making processes, the problem still persist with utilization of micro fines. It is understood that Bailadila mines of NMDC alone account for an estimated amount of 11 Mt of slimes. Besides, substantial amount of fines is also accumulated in different mine sites. Partial utilization of mined output is not only affecting internal resource conservation but also contributing to pollution and environmental problems.*

*In this paper, an attempt has been made to focus on various processes/ technologies available today, utilizing the iron oxide fines and applicability of the same under Indian conditions. Further, based on available information indicative techno-economics have been spelt out.*

**Keywords :** Direct Reduction, Smelting reduction, Macro fines, Micro fines, ROM

### **INTRODUCTION**

Iron ore mines are largely operated by the following organizations in India

- 1) Steel Authority of India Limited (SAIL), New Delhi and Tata Iron and Steel Company Ltd. (TISCO), Jamshedpur

- To cater to the requirements of Sinter Plant and Blast Furnace feed

- 2) National Mineral Development Corporation (NMDC), Hyderabad
  - To meet the export obligations of the country
  - To meet the requirements of Direct Reduction Plants, both coal and gas based
  - The requirements of pellet (for ex. ESSAR etc.) Plants etc.
- 3) Kudremukh Iron Ore Limited (KIOCL), Mangalore
  - Primarily for export
- 4) Chowgules, Dempos etc.
  - Primarily for export
- 5) Others (Private Mines operators like Orissa Mining Corporaiton) etc.
  - For export and also for meeting the requirements of sponge iron plants (For ex Banspani area of Orissa, Barajamda of Bihar etc.)

ROM samples of above contain significant fraction of fines. In addition, fines are also generated during crushing and sizing. Processing of ore is carried out either through wet or dry method. Few have additional washing facilities. In this paper iron bearing fines have been classified into following categories,

- i) Export quality fines
- ii) Iron ore fines generated at mine site and in plants for production of hot metal in Indian blast furnaces.
- iii) Iron ore fines generated in mines and plants of alternative iron making units (Rotary kiln, gas based DRI, Smelting Reduction Plants etc.)

Export quality fines are mostly pelletised (Kudremukh, Mandovi etc.). Fig. 1 indicates utilization pattern of iron ore fines in the country<sup>[1, 6]</sup>.

Coming to iron ore fines generated in connection with Blast furnace Iron Making, the normal sinter feed consists of size range + 0.15mm to - 10 mm. We shall discuss about utilization of iron ore fines of -0.15 mm size.

Due to clayey and sticky nature of Indian iron ores as well as high moisture content, especially in the rainy season, wet processing, consisting of wet screening of -10mm in-conjunction with scrubbing, is the usual practice. In this process the - 0.15mm fraction is rejected as "slime" and does not find any use without beneficiation due to its high alumina content.

According to the various estimates, the quantity of slimes amount to about 14-18 percent of the total ore mined, with alumina content varying between 3 to

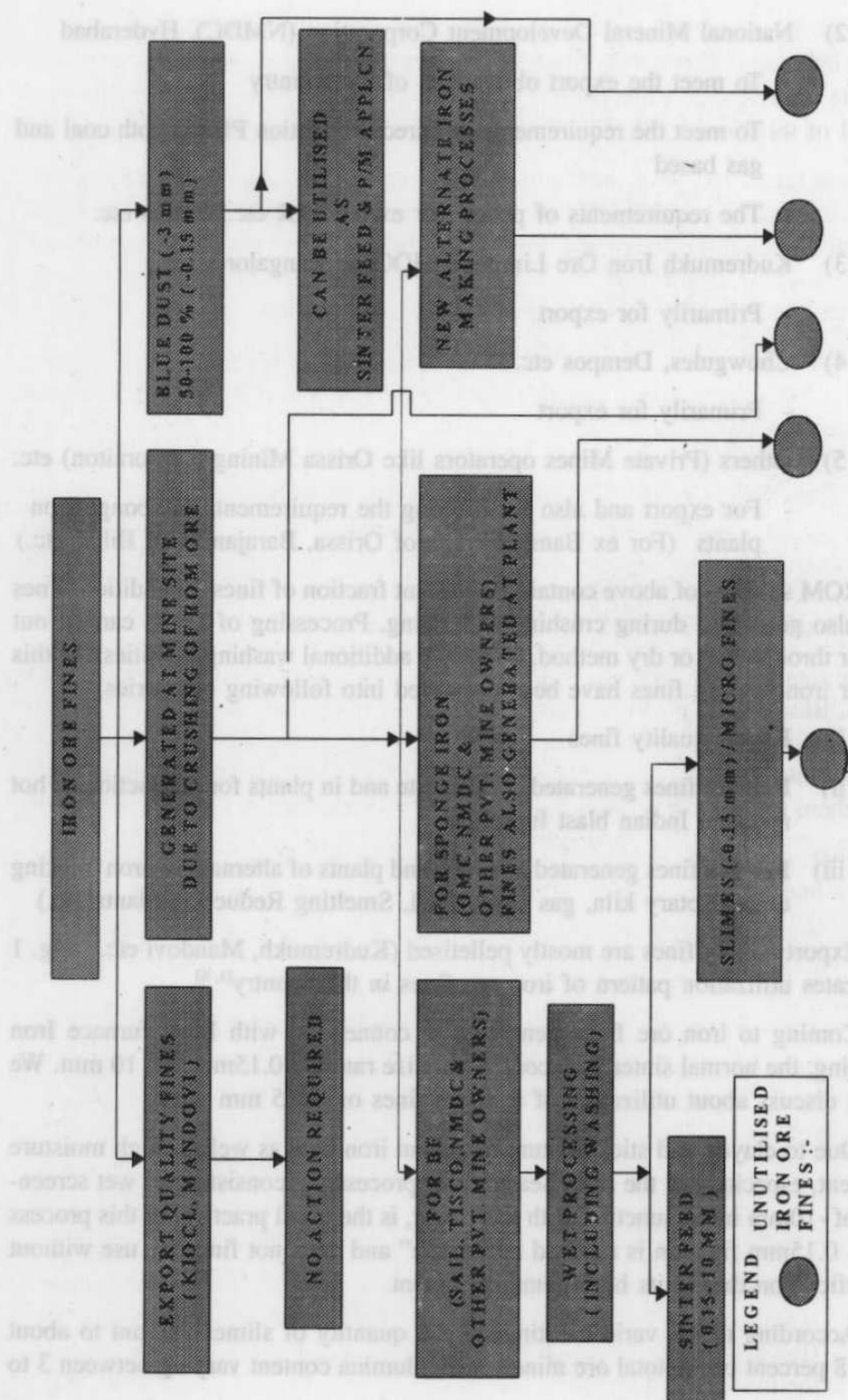


Fig. 1 : Perspective utilisation pattern of iron ore fines in India

5 percent. High alumina content in conjunction with adverse  $\text{Al}_2\text{O}_3/\text{SiO}_2$  ratio of Indian iron ore is harmful to Blast furnace operation. However, in some mines, washing of iron ore is carried out with the objective of lowering the alumina content of the sinter feed. This lead to further rejection of fines as tailings.

These unutilized fines are dumped at the mine sites. As reported, Gua and Bolani iron ore mines of SAIL have dumps estimated at about 10 Million tonnes and 7million tonnes respectively. Further, Bailadila mines of NMDC, is reported to have an estimated 11 Mt of slimes and expected generation in the coming years could be to the tune of 1.5 Mt to 2 Mt per year.

Besides slimes and tailings, Indian iron ore reserves also consist of a large amount of blue dust, which are 100 per cent - 3 mm and principally - 0.15 mm (variously estimated as 50-100 per cent). It is rich in iron content (65-69 per cent total Fe) and low in Alumina (0.6 - 2 per cent). Total blue dust reserve in India is estimated to be around 550 million tones, out of which Bailadila alone accounts for around 200 million tones. NMDC, SAIL, TISCO and a few educational and research institutions have carried out studies on its utilization in iron making. It is understood presently TISCO is using upto 50 percent blue dust in sinter feed and in SAIL, the same ranges between 5-25 per cent.

The total iron ore reserve in India is estimated to be around 12,000 million tonnes. Blue dust constitutes around 5 per cent of the total reserve, and endeavors are being made for economic utilization of the same for iron making. Besides, of late, Blue dust is also finding usage in powder metallurgy applications. Even then, there will be enough blue dust left for use in DR and SR processes.

Hence, so far as utilization of iron ore fines is concerned, the following sources may be considered.

- i) Slimes and tailings of iron ore mines of integrated steel plants and NMDC (Size - 0.15 mm).
- ii) Fines for the up coming SR processes from the sources indicated above.
- iii) Iron ore fines generated in mines and plants for rotary kiln and shaft furnace based sponge iron production. For the former fines may be defined as -3mm and for the latter -6mm and finally
- iv) Effective utilization of blue dust.

Further, the following points are also worth considering

- i) Present environmental regulations require containment of fines dumped at mine site by walls (as required), covering with topsoil and greenery. However, it is certainly better, if fines are not dumped at all and utilized for iron making.

- ii) Utilization of fines leads to conservation of minerals as well as better economics of operation.
- iii) Long range transportation of fines should be avoided for economic and environmental reasons.
- v) Availability and price of steel scrap may continue to be problematic for India.

Therefore, endeavor should be to utilize fines to the maximum extent economically viable.

### **Processes for Utilization of Iron Oxide Fines**

Quite a few Direct Reduction (DR) processes using iron oxide fines have already found commercial applications till date. Among the Smelting Reduction (SR) processes, only Romelt has reached the state of commercialization till date, though a few on the horizon appear to be promising. In the following paragraphs, a brief review of the processes<sup>[2]</sup> and their relevance under Indian conditions have been undertaken.

#### **Direct Reduction Process**

Among the DR processes, which are capable of using the iron oxide fines and have already been developed or are in advanced stages of development mainly encompass FINMET, FASTMET, CIRCOFER, CIRCORED and Iron Carbide processes. An overview of the various processes and current status is indicated in Table 1 and indicative investment and production costs vide Table 2 respectively.

It can be observed that among the processes<sup>[3,6]</sup> mentioned, FINMET, Iron Carbide and CIRCOFER are already commercialized. Noamundi blue dust has already been tested in the pilot plant at Golden, USA for iron carbide production and encouraging results has been obtained. Similar trial runs with Indian raw materials and techno-economic study based on the test data can be made to evaluate the other processes under Indian conditions. However, problem lies elsewhere. All these processes are based on natural gas, which is available in the coastal areas and in the northeast. This may impose some restriction regarding location. Further, there is no additional allotment of natural gas by the Government forthcoming in near future. Consequently, likely- hood of these processes dotting India's map is remote.

FASTMET process, using non-coking coal promises a simple and economical approach to hot DRI production to be used for making pig iron or steel. It combines proven unit operation and equipment into a reliable iron making system and offers greater flexibility. These, however are still claims, as the process

Table 1 : Current status of selected direct reduction process

FINMET	FASTMET	CIRCOFER	CIRCORED	IRON CARBIDE
<p>A 2 Mtpy HBI plant at Port Headland in the Pilbara region of Western Australia was commissioned in February 1999. Full production is expected in early 2001. Current focus is on obtaining mechanical reliability and consistent operation to be followed by process optimization</p> <p>A further 2.2 Mtpy capacity is being constructed at Puerto Ordaz, Venezuela. The output from this plant will supply US and European EAF steel making markets.</p>	<p>Midrex and Kobe steel have operated a 2.5 tpy, 8.5 m OD hearth demonstration plant at Kokogawa Steel Of Kobe Steel works in Japan since 1995.</p> <p>It is understood that world's first commercial scale iron bearing waste recycling plant using FASTMET process will begin operation towards the 2nd half of 2000, at Nippon Steel Corporation's Hirohata Works in Himeji, Hyogo Prefecture, Japan.</p> <p>The plant will have a nominal capacity to process 190,000 tpy of iron bearing waste. The 140,000 tpy DRI produced will be charged then to BOF at the Hirohata Works.</p>	<p>Lurgi in Frankfurt has set up a Circofer pilot plant with a fine ore throughput capacity of 5 tpd and coal of 2 tpd. It has been designed as a two-stage plant with a CFB and integrated heat generator followed by a FB reactor. The plant is being used for testing specific iron ores and coals to develop design parameters and simulate operating conditions for industrial plants.</p>	<p>A 500,000 tpy HBI Circored plant (Joint venture of Cleveland Cliffs, LTV steel and Lurgi) was commissioned in May 1999 at Trinidad and reported to be facing some teething problems and have not been able to achieve sustained levels of briquette production. However, it is claimed that material produced so far is able to meet quality expectations including high metallization rate.</p>	<p>World's first commercial plant of capacity 300,000 tpy, built by Nucor Corporation, USA was commissioned at Trinidad in 1996. The plant is reported to face a series of operating problems, both mechanical and operational, and never worked beyond 60 per cent capacity. As per available information, the plant has been shut down.</p> <p>A larger plant of 600,000 tpy capacity is presently under construction by Qualitech Steel Corporation, Texas, USA.</p>



is yet to be commercialized. Testing of raw materials needs to be carried out before adoption of this process in India. CIRCOFER is still in the pilot plant stage. Trial runs with Indian raw materials need to be encouraged, as sufficient quantity of iron ore fines including blue dust besides significant amount of non-coking coal available in the country could be gainfully utilized.

*Table 2 : Indicative investment and production cost of selected direct reduction process*

Sl. No.	Process	Specific Investment	Production cost including	Remarks
1	FINMET	225-245	95-110	
2	FASTMET	175-190	100-105	
3	CIRCOFER	200-215	85-90	
4	CIRCORED	190-205	80-85	
5	IRON CARBIDE	225-245	90-105	

### Smelting Reduction Processes

The various SR processes, which appear promising as far as utilization of iron ore fines, are considered are Romelt, Dios, Ausmelt and Hismelt.

Outline of the processes, present status, indicative investment and production costs are indicated in Table 3 and 4 respectively.

Romelt process<sup>[4]</sup> appears to be promising under the Indian context and a 300,000-tpy pig iron plant, using slimes from Bailadila is being set up by NMDC in the Bastar district of Madhya Pradesh. However, while evaluating the process under Indian context, the following points need deliberations.

Smelting trials conducted in Russia were primarily with a variety of ores with low alumina load while the ash load through coal was also low. This is not the case in India. The Indian iron ores are characterized by high alumina to silica ratio. Use of such ore in blast furnaces leads to formation of viscous slag resulting in higher coke rate and working of the furnace at lower basicities compared to European or Japanese furnaces leading to lower productivity and inferior hot metal quality (Higher Si content etc.). Processing of such ore in the Romelt process circumvents these limitations. The quality of hot metal is claimed superior (very low Si and Mn content). Besides, Romelt technology permits use of sinter feed as well as iron ore fines. Consequently, part of large amount of fines generated at mines pithead could be used without agglomeration.

Table 3 : Current status of selected smelting reduction process

ROMELT	DIOS	AUSMELT	HISMELT
<p><b>Current Status</b></p> <p>A large-scale pilot plant (Capacity 300,000 tpy) is operating intermittently at Novolipetsk, Russia. The process has since been licensed to M/s. ICF Kaiser, USA &amp; Nippon Steel Corporation, Japan. Romelt SAIL India Pvt. Ltd. (RSIL), a joint venture of Steel Authority of India Ltd. (SAIL) and Russian companies such as AMET Ltd., MISA and NLSW is responsible for marketing the process in India, South East Asia, China, Middle East and other countries.</p> <p>A pig iron plant of 0.3 Mt/Yr. capacity based on the process is being set up by NMDC, Hyderabad at Bailadila region of MP, India by NMDC.</p>	<p>Based on the individual elemental study results a pilot plant of 500 tpd was constructed in NKK's Keihin works during 1993. Until January 1998, ten (10) test campaigns have been carried out.</p> <p>Based on the test results in pilot plant, feasibility studies for setting up commercial Dios plant of capacity 100-400 t/h has been carried out by M/s. NKK Japan and found to be economically attractive compared to conventional BF process of iron making. Process awaiting commercialization.</p>	<p>Ausmelt Ltd., based near Melbourne in Australia has developed and patented this technology for production of hot metal. Ausmelt has conducted extensive campaigns in the 1 tpd pilot plant for over five years. Plants are a foot for a 2 tpd demonstration plant campaign to establish design and operating parameters required for scaled up operation at a commercial scale.</p>	<p>Hismelt was originally developed as a horizontal (refractory lined) vessel. Extensive testing at a scale of 100,000 t/a at Kwinana, Australia revealed serious difficulties with refractory. Since 1997, a new vertical (water-cooled) smelter has been in operation. This new system is reported to have solved the refractory wear problem and significantly enhanced efficiency. Further it is claimed that engineering robustness has been demonstrated in a 38 day trial with &gt; 90% plant availability.</p> <p>The development strategy involves scale up in two steps. The first is construction of a 6m ID demonstration plant, which represents a scale up by a factor of 5 and commercially viable in its own right. There is also a desire to re-use fine revert materials from integrated steel plants and where the hot metal (around 0.4 - 6 Mtpy) can be utilized in downstream processing. Successful operation and demonstration to pave way for 8 m SRV units</p>



Table 4 : Indicative investment and production cost of selected smelting reduction processes

SL. NO.	PROCESS	SPECIFIC INVESTMENT US/\$	PRODUCTION COST INCLUDING CAPITAL RELATED CHARGES, US/\$	REMARKS
1	ROMELT	<b>405-410</b> <b>Main plant facilities</b> Module : 2X20-24M2 bottom area of working Chamber Oxygen Plant: 2X1200tpd Power Plant : 80 MW Hot Metal : 600, 000 tpy	145-155	The investment covers main plant facilities along with raw material handling system, services and utilities, land, site development, interest during construction, pre operative expenses, contingencies but excluding infrastructure.  Note: The site considered is in the Bastar region of MP

In the absence of volume of work and reliable process parameter data under Indian conditions, techno - economics of the Dios, Ausmelt and Hismelt process could not be carried out. However, based on the feasibility study of a 6000 t/d or 2 Mt/Yr. facility, it has been claimed that the capital cost for a Dios plant could be reduced by 35% and production cost by 19% in comparison with a blast furnace complex of similar capacity. (The specific investment and production cost for a Blast Furnace Complex including matching coke ovens and sinter plant is in the range US \$ 140-160 / t and US \$ 130-140/t respectively). As per available literature, the specific investment cost projected for a 8M \* HI smelt plant would be around US\$ 140-190/t and the production cost for the same US \$ 75-95 / t respectively.

\* The number designation refers to active bath diameter.

The process developer claims that non-coking coal available in India may find use safely in the Romelt process. At the same time the qualities of non-coking steam-coal is not an obstacle. Thus, the iron ore and fuel conditions in India seem favourable for iron making through Romelt technology. However, the high alumina and high ash loading in the bath would call for determination of appropriate process thermodynamics particularly with respect to slag chemistry and sulfur content of hot metal. A modified reactor to accommodate large volume of slag and metal may be desired.

Romelt plants of small capacity (from 100,000 - 300,000 tpy) incorporated in mini steel plants would provide opportunity to enable EAF steel maker with quality hot metal and provides an economical alternative to the expensive scrap. However, it is to be noted that there are few secondary producers in India who can use 0.1-0.3 Mt/yr. hot metal in their EAF.

Considering the advantages claimed like installation of high capacity unit (1.0 Mt and above), flexibility in use of non-coking coal of different grades, use of fine (sinter feed) ore, controlled pre-reduction and post combustion depending on quality of input material, it appears Dios process may be a suitable iron making technology under Indian conditions. The authors had a fruitful discussion with NKK on the process. It was impressed upon them that testing of Indian input materials in the pilot plant and extensive study of bath metallurgy needs to be carried out to ascertain suitability and viability of the process.

The Ausmelt process appears to be suitable under Indian condition considering the claims by the process developer. However, the process is still at pilot plant stage and development of commercial design may take some time. Life of lance and refractory materials, effective utilization of off gas, preparation of raw materials, etc. are certain factors that will determine the commercial viability of the process. This process may be kept under observation and steps for adoption may be taken at an appropriate time.

Hismelt process<sup>[5]</sup> has already achieved a post combustion level of 60% and heat transfer efficiency of 90%. This is very close to optimum smelting reduction (SR) process. This process may have a good future in India if different types of coals available are used and requirement of natural gas is eliminated by the process developers. However testing of Indian raw materials and subsequent feasibility study needs to be carried out before installation of this process in India can be thought of.

## CONCLUSIONS

- i) Deployment of extensive mechanized mining and advanced beneficiation techniques are resulting in generation of fines, both micro and macro

in various mine sites of the country.

- ii) Though macro fines and blue dust is finding its use through various agglomeration techniques, problem still persists with micro fines/slimes.
- iii) The partial utilization of mined out put not only affects internal resource conservation but leads to pollution and environmental problems.
- iv) A few Direct Reduction and Smelting Reduction processes have come up for fines utilization, which calls for critical review from the Indian point of view.
- v) Utilization of fines for iron making to an optimum extent will not only improve economics of mining operation but also enable the country to be less dependent on scrap, whose fluctuating price always affects the market.

## ACKNOWLEDGEMENT

The authors wish to acknowledge the kind permission accorded by MECON management for presenting/publishing the paper and the efforts of all those who participated in preparation and finalization of the paper.

## REFERENCES

- 1. Ghosh A. and Datta S. K., (1999), "Alternative iron making processes and cold bonded iron ore - coal /char composite pellets", IIM Metal News, Volume II, No.2.
- 2. Sharma B. and Frauen R. J., (1998), "A review of coal based iron making processes", ICSTI/Iron Making Conference Proceedings, p. 1537.
- 3. Brent A. D., Mayfield P. L. J. and Honeyands T. A., (1999), "The port hedland, FINMET project - fluid bed production of high quality virgin iron ore for 21st Century", ICARISM'99, p. 111, Perth, WA.
- 4. Bhattacharya P.*et. al.*, (1999), "Emerging technologies for iron making - An Indian perspective", ICARSIM'99, p. 151, Perth, WA.
- 5. Macauley P. and Price D., (1999), "Hismelt - a versatile hot iron process", Steel Times International, p. 22.
- 6. In-house information.